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Workshop for Consensus in OA Imaging
Review of the anatomical and radiological differences between fluoroscopic and non-fluoroscopic positioning of osteoarthritic knees

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Summary

Objective: To determine the differences in the radioanatomical appearance of the tibiofemoral compartment in knees radiographed in the fluoroscopic semiflexed, semiflexed MTP and fixed flexion methods compared to that obtained in the extended knee position. To assess the differences in the radiological procedures between the fluoroscopic and nonfluoroscopic semiflexed methods of radiography.

Methods: Based on anatomical principals to describe the differences in (1) the content of the joint space in knees radiographed in the extended and semiflexed positions and (2) the sectional plane for joint space width (JSW) measurement in radiographs of knees positioned in the extended, fluoroscopic guided semiflexed, MTP and fixed flexion positions. From published procedures to determine the factors that affect study costs, X-ray technologists operating time and film processing in fluoroscopic and nonfluoroscopic methods of radiography.

Results: Medial compartment JSW from semiflexed methods only accurately measures cartilage thickness. All semiflexed methods reproducibly reposition the joint within any one patient. The angle at the tibiofemoral joint varies little between patients in the fluoroscopic semiflexed, less in the MTP and more so in the fixed flexion positions; the latter is due to the effect weight-associated differences in thigh girth. The sectional plane of JSW measurement is generally similar within the three views. Compared to the fluoroscopic method the radiological procedures of the nonfluoroscopic techniques were less demanding.

Conclusion: The MTP and fixed flexion methods are much easier to use than the fluoroscopic method. They reproducibly reposition the knee within patient knees and between knees in the MTP but less so in the fixed flexion view.

Key words: Knee, Osteoarthritis, Radiography, Joint Space Width.

Introduction

Knee radiography produces an image of the joint in which the anatomical structures are identified by the differential absorption of the X-ray beam by the tissues. The radiograph is not reality, it is a 'shadow image' and knowledge of anatomy is needed to identify the different features within the image. Further, the role of anatomy is important in recognizing the effect normal anatomical variation has on the radiographic appearance of the joint and how structural changes in the joint with advanced disease, such as subluxation associated with ligament laxity, can affect joint space width (JSW) assessment. An example of the former, affecting the size and shape of the joint space, is the degree of posterior inclination of the medial tibial plateau, which can range from horizontal (0°) to 10° with a mean of 7°[1,2]. The effect of these and other factors are described in the sections relating to JSW assessment.

Primary outcome measures in clinical trials for knee osteoarthritis (OA) that employ radiography to assess the effect of structure modifying OA drugs (SMOADs), quantify changes in tibiofemoral articular cartilage thickness from measurements of JSW[3,4]. This space is a gap between bones, the contents of which is determined by the material thickness of articular cartilage and its compressibility when the joint is radiographed in the standing position[5]. The radiographic assessment of the contents of the joint space are controlled by the following criteria:

- The anatomical position of the knee, whether in the extended or semiflexed position.
- The sectional plane for JSW measurement, which should coincide with the site of load transmission across the joint and should be similar within and between patient examinations[6,7].

Consistency in controlling these aspects of the radiographic procedures are necessary to ensure precise measurements of the JSW that are required to determine OA progression in knees from longitudinal studies. This paper describes the effect that these criteria have upon the appearance of the radiographic joint space obtained from three protocols under consideration at the Workshop for Consensus in OA Imaging at the meeting in Bathesda, December 2002: the fluoroscopic semiflexed knee view[8,9] (Fig. 1A) and the two methods without fluoroscopic assistance for positioning the joint, MTP[7] and fixed flexion[10] (Fig. 1B & C). The protocols for positioning the knee using these methods are described in their original publications as well as in a recent review[11].

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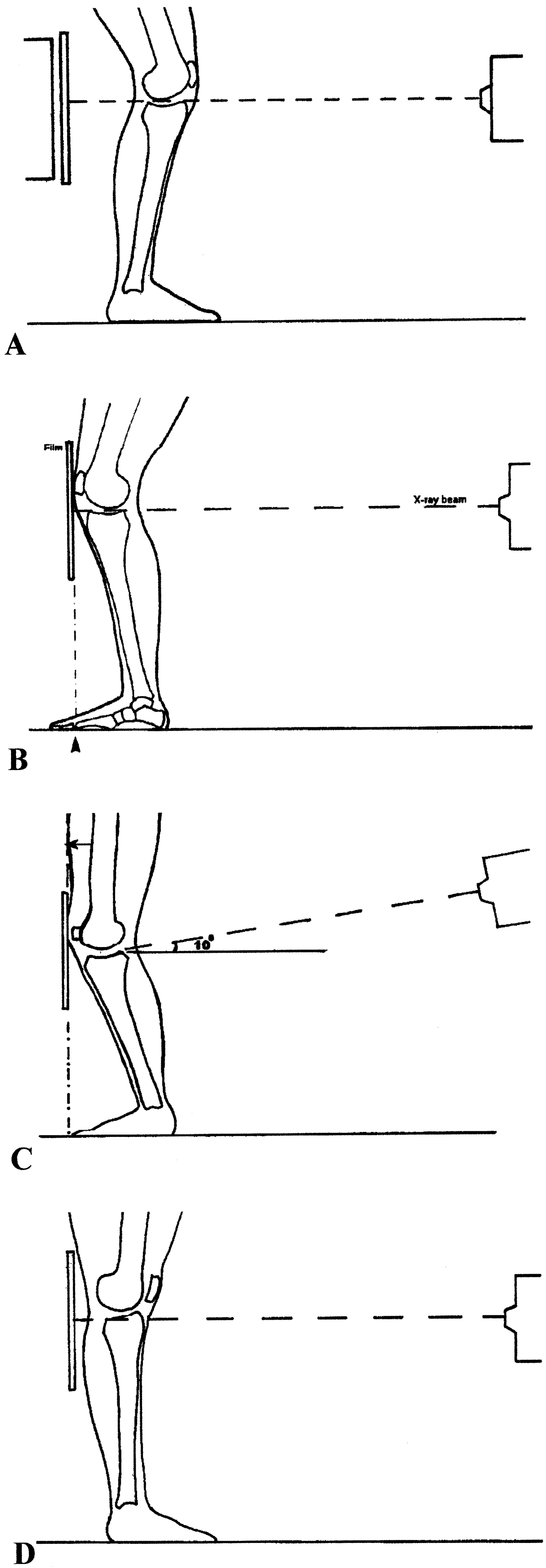

Comparison between the radiographic methods

CONTENTS OF THE JOINT SPACE WIDTH

All three protocols under consideration place the knee anatomically in a semiflexed position. This is achieved by flexing the knee so that the angle subtended between the tibial shaft and the vertical has an average (SD) 7° (2.8°)[6,12] in the fluoroscopic semiflexed, between 7°–10° in the MTP[7,11] and between 20°–30° in the fixed flexion[10,11] views respectively. Although there is no published data on the angle subtended between the femur and tibia in these three positions, measurements undertaken of the anatomical disposition of the joint indicates that the angle at the joint in the semiflexed fluoroscopic and MTP are similar, ranging between 170°–155° and 165°–150° respectively, and slightly narrower in the fixed flexion position, between 155°–140°. The significance of the semiflexed position for assessing articular cartilage thickness and the sectional plane for JSW measurement is illustrated by comparison with the standing extended knee view[6,12].

In the extended position (Fig. 1D) the knee is 'locked into a straight leg stance'[12], which in patients can range from mild flexion to a genu recurvatum. The femoral condyles role forward onto the anterior edge of the tibial plateau so that the weight of the body is transmitted across the joint, anterior to the attachment of the collateral and cruciate ligaments[13–15]. With the knee in extension, the body's weight passes down at the anterior region of the joint and is counter-balanced by the tension in the collateral and cruciate ligaments[2,13,14]. In this position the medial compartment JSW comprises the combined thicknesses of the femoral and tibial articular cartilages as well as that of the meniscus (Fig. 2A). The tissues at this site are not under load during normal walking and hence the assessment of their thickness does not reflect the status of the tissue that the patient uses during regular ambulatory activity. In knees without any cartilage covering the medial tibio-femoral articulating surfaces, a radiographic joint space is still visible in the medial compartment as the femoral condyle rests on the anterior tibial rim[6,12,16] (Fig. 2B) providing a false impression of the joints disease status. Further, because of the normal variation in posterior inclination of the medial tibial plateau[1,2], the appearance of the joint space, with knees in full extension, will vary between patients. Only a small percentage of the knee radiographs will exhibit parallel alignment between the medial tibial plateau and the central ray of the X-ray beam, as found by Mazzuca *et al.*[17] in a study of standard radiographs from several clinical centres.

In the semi-flexed knee position[7–10], the medial femoral condyle occupies a central position on the articular surface of the tibia[13–15]. In this position the medial compartment JSW comprises the combined thicknesses of the femoral and tibial articular cartilages; the meniscus is excluded from the site of minimum JSW measurement[18,19] (Fig. 3B). In knee OA, JSW measurements correlate with the combined thickness of the femoral and tibial articular cartilages (*r*. 0.91) and thus accurately and reliably measure

Fig. 1. Diagrams illustrating the relationship between the anatomical position of the knee, the alignment of the central ray of the X-ray beam with the tibial plateau and the film/cassette in (A) fluoroscopic semiflexed position; (B) MTP view, with the first metatarsophalangeal joint positioned below and in line with the front of the film/cassette; (C) fixed flexion view, with the big toe in line with the front of the film/cassette and 10° X-ray beam angulation; (D) anteroposterior extended knee view.

A


B


Fig. 2. In the extended knee position the femoral condyle roles onto the anterior rim of the tibial plateau, in this position the joint space comprises the combined thickness of the femoral, tibial and meniscal cartilages, as shown in (A) a sagittal MRI scan of the medial tibiofemoral compartment and in (B) a lateral radiograph of an OA knee where the loss of cartilage results in the condyle resting on the bony ridge of the tibia producing a true space visible in the centre of the compartment.

articular cartilage thickness[5]. In the semiflexed position the articular cartilages are under direct load as the site of JSW measurement co-inside with that of the principal forces acting across the joint[13–15]. Thus JSW measurement reflects the status of the articular cartilage the patient uses during normal walking[2]. It is also the site at which arthroscopy has revealed highest prevalence of articular cartilage destruction[20].

SECTIONAL PLANE FOR JSW MEASUREMENT IN DIFFERENT KNEE POSITIONS

The appearance of the radiographic joint space is defined by the X-ray beam's projection of the bony margins of the femur and tibia onto the film. This projection defines the sectional plane for JSW measurement and is determined by the relationship between the angle of alignment of the X-ray beam (whether horizontal or inclined downwards) and the anatomical position of the knee, relative to the film and cassette. The anatomical position of the knee, the sectional plane for JSW measurement and its relation to the site of load transmission in the joint are best understood from diagrams of the joint in the sagittal plane (Fig. 4).

In the extended knee position the measurement plane of the joint space is outside the site of load transmission across the joint[13,14,21]. The JSW is wider at the plane of measurement than at the site of load transmission (Fig. 4A & Fig. 2A). JSW measurement is also subject to parallax

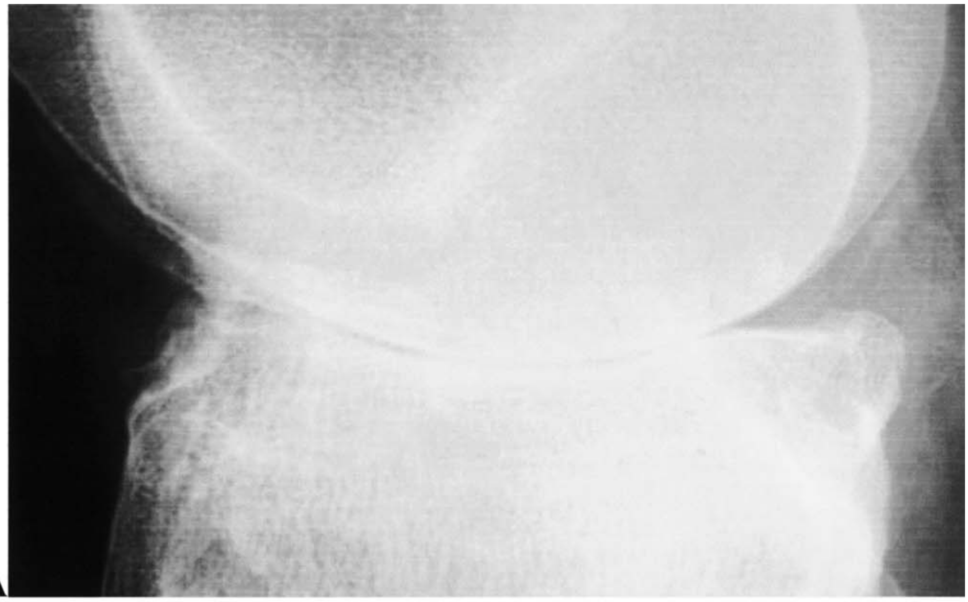

Fig. 3. In the semiflexed position the femoral condyle occupies the central region of the tibial plateau. (A) is the same knee as in Fig. 2B radiographed on the same occasion in the semiflexed position confirming the absence of cartilage in this OA joint. (B) Double contrast macroarthrogram of an OA knee taken in the standing semiflexed position. In the medial diseased compartment the meniscus (M) is extruded so that the minimum joint space width measures only articular cartilage thickness.

error since the sectional plane for this measurement is not parallel to the film.

In the semiflexed knee position (either fluoroscopic guided positioning or with the non-fluoroscopic MTP view), the sectional plane for JSW measurement coincides with the site of load transmission across the joint[13–15,21] (Fig. 4B). The plane of JSW measurement is parallel to the film and perpendicular to the femoral and tibial margins.

Although the radiographic procedure for the fixed flexion position is different from that of the semiflexed MTP method, nonetheless, the sectional plane of measurement is similar between these two views for any one knee (Fig. 4B & Fig. 4C). Positioning the knee in the fixed flexion position[10] results in a forward rotation of the limb. Placing the patella against the film-cassette standardizes the angle of the tibia to between 20°–30°. With the anterior displacement of the femur to bring the thigh in contact with the template and film-cassette, the angle subtended between the femur and tibia is increased so that the angle at the this joint increases from that present in a flexed or tunnel view of the knee to an angle that is similar to the semiflexed fluoroscopic and MTP views (155°–140°; c.f. previous section). The downward angulation of X-ray beam in the fixed flexion position aligns the tibial plateau with the center of the X-ray beam producing an image similar to that of the other semiflexed views. However, in the fixed flexion view JSW measurement is subject to parallax error since the sectional plane of measurement is not parallel to the film (Fig. 4C).

Reproducibility in the anatomical positioning of the knee for JSW measurements

ANATOMICAL DIFFERENCES BETWEEN FLUOROSCOPIC AND NON-FLUOROSCOPIC METHODS

Standardization of the radioanatomic position of the knee in the semiflexed view employs either fluoroscopic guidance for positioning the knee during radiography or non-fluoroscopic procedures that dependent upon the use of standard radiographic equipment. Radioanatomically both protocols fix the degree of joint flexion in the antero-posterior plane and joint rotation in the medio-lateral plane so that the position of the joint is similar within and between patient examinations. However, there are anatomical differences between the different radiographic views that affect the appearance of the joint space, as described below.

STANDARDIZATION OF KNEE FLEXION IN THE ANTERO-POTERIOR PLANE

Semiflexed fluoroscopic method

Under fluoroscopic guidance, the technologist positions the knee by aligning the central ray of the horizontal X-ray beam with the medial tibial plateau so as to superimpose the anterior and posterior tibial rims[7,8] (Fig. 1A). The medial tibial plateau will thus appear horizontal and parallel to the X-ray beam (Fig. 5 B). Anatomically the effect of standardizing the angle of the tibia by using fluoroscopy will result in a similar angle at the tibio-femoral joint for repeat examinations within a patient, so that the sectional plane for JSW measurement is similar within patients. Although, the angle at the tibio-femoral joint will differ between patients due to the normal variation in tibial plateau inclination[1] (Fig. 5A), the work of Freeman and colleagues[13–15] has shown that such variations in the degree of knee flexion have little effect upon the sectional plane for JSW measurement between patients (Fig. 5B).

Semiflexed non-fluoroscopic MTP method

The technologist places the legs in a fixed position relative to the film, the feet (i.e. the first metatarsophalangeal (MTP) joint of each foot is positioned immediately below and in line with the front edge of the film cassette) and the horizontal X-ray beam is aligned with the joint

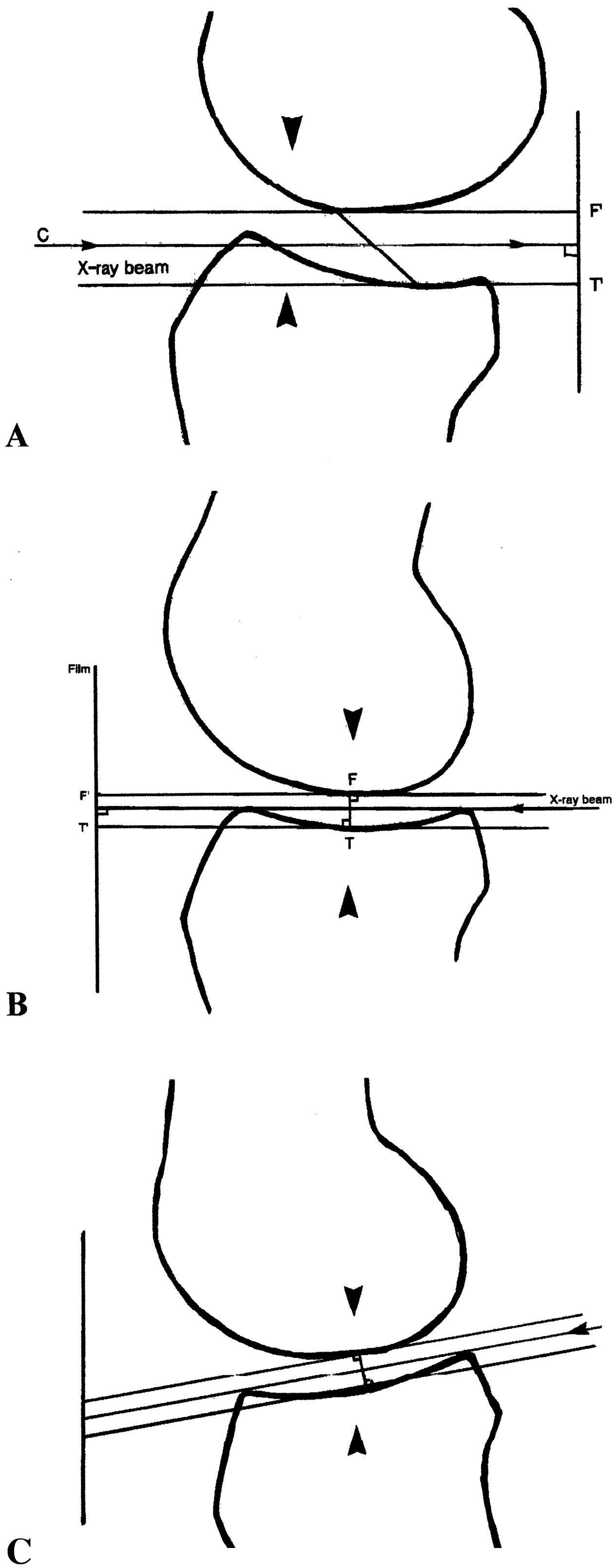

Fig. 4. Diagrams of the anatomical position of the femur and tibia in the radiographic views of the knee in (A) extended, (B) semiflexed MTP and (C) fixed flexion positions. The arrowheads indicate the site of load transmission across the joint. The line crossing the joint space identifies the sectional plane for JSW measurement, which does not coincide with that of load transmission in the extended view (A). A parallax error is present in (A) and in (C) as the plane of JSW measurement in these views is not parallel to the film.

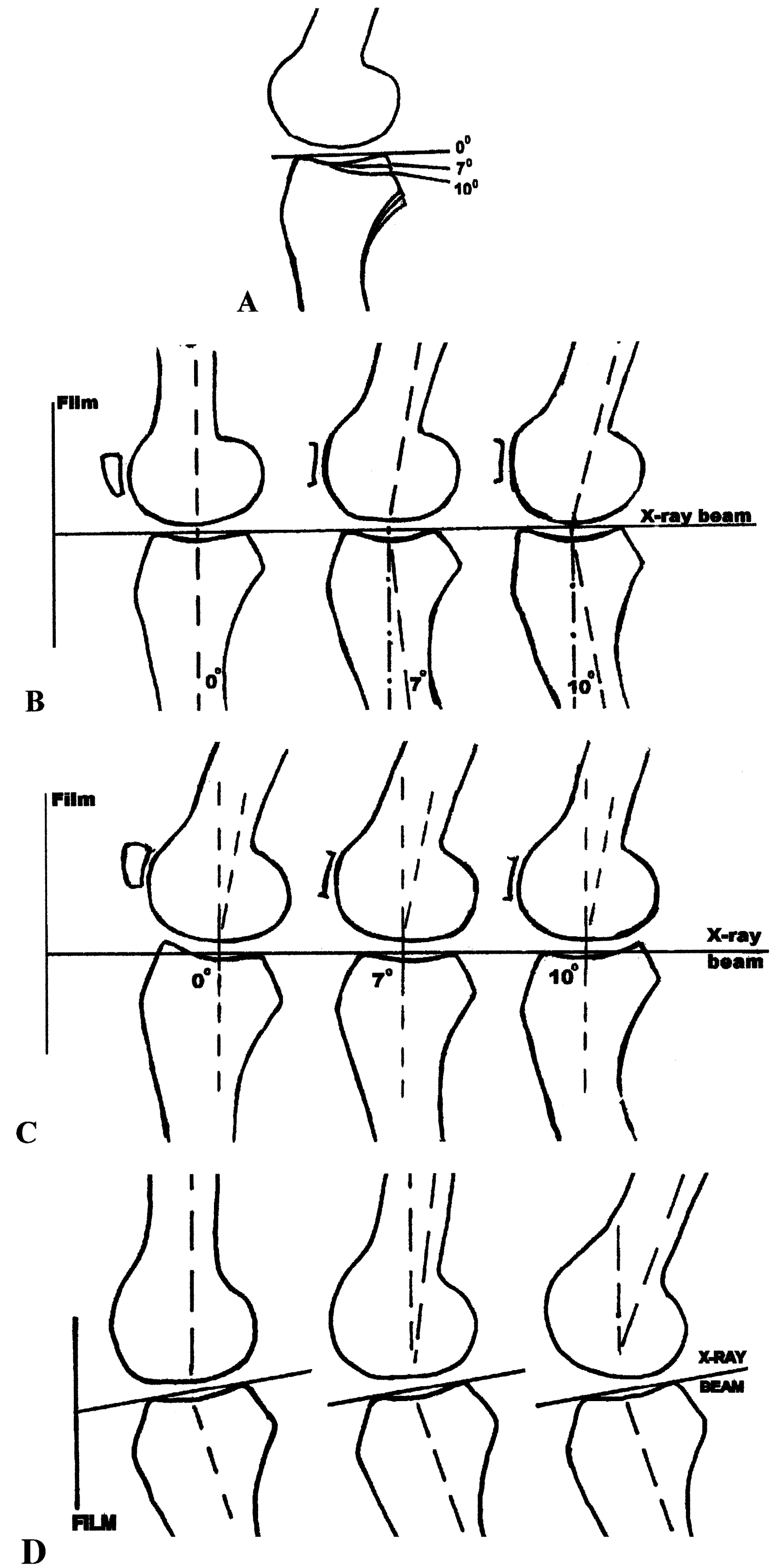

Fig. 5. (A) illustrates the normal variability in the posterior inclination of the medial tibial plateau between knees. The effect of this anatomical variation in the fluoroscopic semiflexed view (B) results in small differences in the tibiofemoral angle of flexion between knees as the tibial plateau is aligned with the horizontal X-ray beam; in the MTP view (C) the tibiofemoral angle is fixed by the radiographic position, this results in small variations in the appearance of the tibial plateau between knee radiographs (see Fig. 7); in the fixed flexion view the effect of differences in thigh girth between patients (see Fig. 6 and text) upon the tibiofemoral angle of flexion is far greater than that due to normal variations in the inclination of the medial tibial plateau.

space[7]. Anatomically the effect of standardizing the angle of the tibia by this method results in the angle at the tibio-femoral joint being similar within and between patients at successive radiographic examinations. Because of variability in the posterior inclination of the medial tibial plateau[1] the radiographic appearance of the medial tibial plateau will vary between patients as determined by the posterior inclination of the tibial plateau (Fig. 5C). Since the angle at the tibio-femoral joint is similar between patients this also ensures that the sectional plane for JSW measurement is similar both within and between patients.

Semiflexed non-fluoroscopic fixed flexion method

The technologist places the legs in a fixed position relative to a template (which incorporates the film and foot positioning device) with the front of each big toe of each foot positioned immediately below and in line with the front edge of the film cassette. The patient leans forward bringing the front of the thigh in contact with the template and the X-ray beam is directed downwards by 10° at the back of the joint. Anatomically, standardizing the angle of the tibia by this method results in the angle at the tibio-femoral joint being similar within patients at successive radiographic examinations. However, the patient's body weight and in particular their thigh girth will determine the degree of flexion at the tibio-femoral joint, i.e. patients with large thighs will have a greater degree of joint flexion (Fig. 6). Thus, a far greater variability in joint position between patients is obtained (Fig. 5D) compared to that in the two previous methods in which the anatomical variability among patients is due to the degree of posterior inclination of the medial tibial plateau. Nonetheless, Freeman and colleagues[13–15] have shown that such variations in the degree of knee flexion may have little effect upon the sectional plane for JSW measurement between patients. However, those joints with

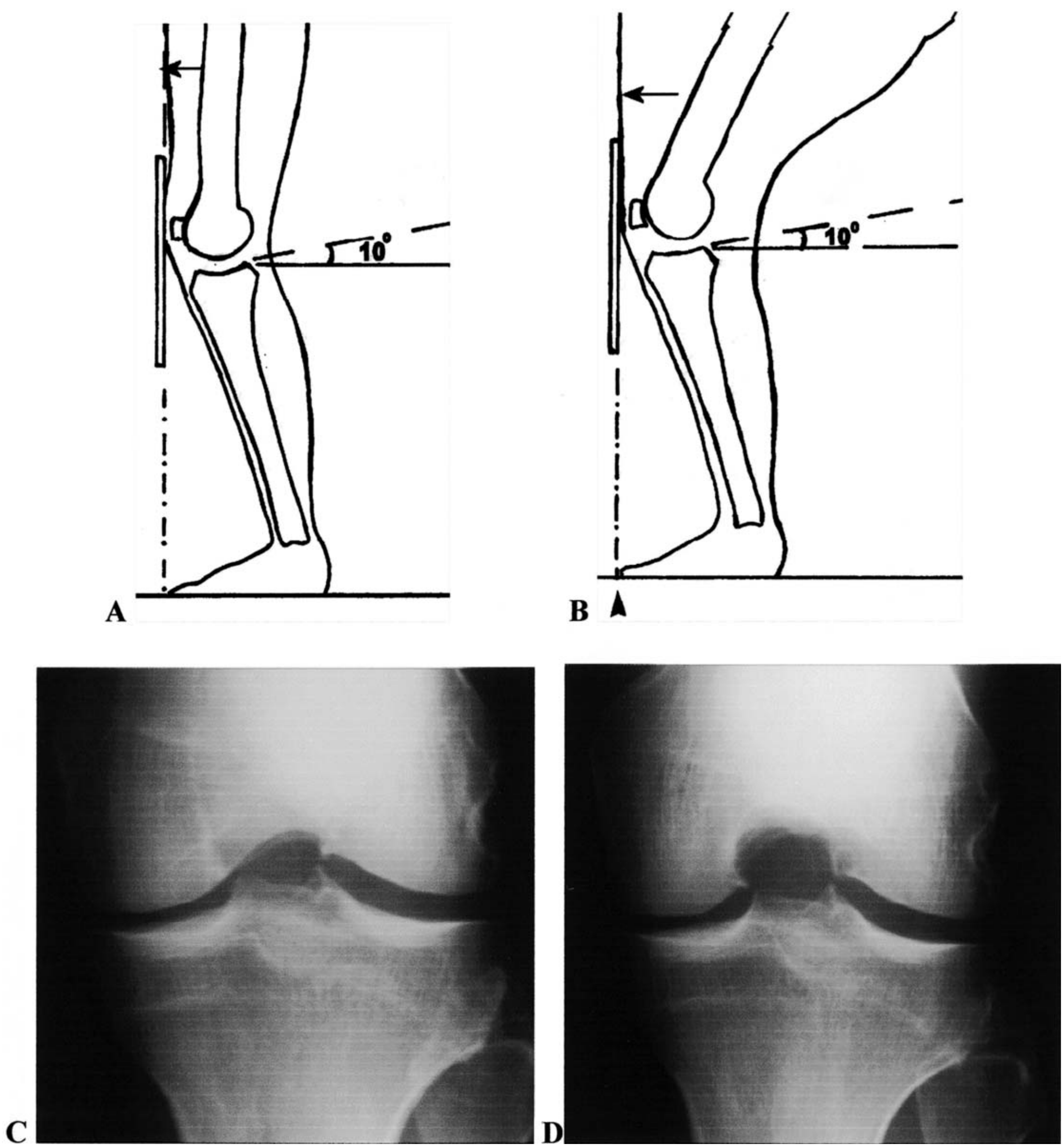

Fig. 6. Difference in the girth of a patient's thigh produce marked alteration in the tibiofemoral angle of flexion between patients. Within the range of mild to modest thigh girth (A) the tibiofemoral angle of flexion results in a radiographic image similar to the fluoroscopic semiflexed and MTP views (C); with greater thigh girth (B) the resulting radiographic image is similar to a Schuss/tunnel view (D).

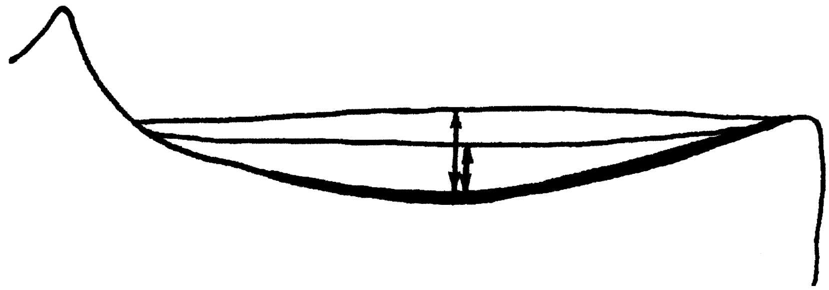

Fig. 7. Diagram of the radiographic appearance of the medial tibial plateau showing the measurements taken, in each radiograph, from the floor of the articular fossa to the anterior and posterior rims respectively. Under fluoroscopic guidance correct radioanatomic position is obtained when both rims appeared superimposed in the X-ray image; with the non-fluoroscopic methods reproducible radioanatomic position is obtained when the distance between the rims is similar at repeat examinations.

a large thigh the radiographic view of the joint is similar to the Schuss/tunnel[7]. Knee joints positioned in the latter view are less reproducibly repositioned than knees radiographed in the MTP or extended knee views, although the reproducibility of minimum JSW was lower but not significantly different from that in the MTP view[7].

Overall it can be considered that none of the three protocols actually ‘control’ the amount of knee flexion since they do not prevent small changes in the angle between the tibia and femur occurring at repeated examinations in long-term studies. These variations are determined not only by the parameters that are used to define the radio-anatomic position of the joint, such as the inclination of the tibial plateau in the fluoroscopic semiflexed view, the foot and tibial length in the MTP and foot, tibial length and thigh girth in the fixed flexion view but also by the amount of pain experienced by the patient and their comfort with the procedure. The effect of these factors on the degree of flexion actually achieved, and its variability between subjects with each protocol is a question for which there is no good data at present.

STANDARDIZATION OF KNEE ROTATION IN THE MEDIO-LATERAL PLANE

The extent to which the knee is medio laterally rotated during radiography is determined by the position of the foot and in particular the extent to which the foot is medially or laterally rotated. All radiographic methods standardize the position of the feet. Under fluoroscopic positioning, the foot is rotated so as to centre the tibial spines below the femoral notch. In the non-fluoroscopic MTP and fixed flexion methods the feet are laterally rotated so that the angle subtended between the inside of the feet is between 15° and 20°[7–10]. In the fixed flexion method the positioning frame determines the angle of the feet. For all methods, foot maps are used to facilitate foot repositioning minimizing differences in knee rotation between visits. Experimental studies have shown that joint rotation has to be large, greater than 15° from the optimum position to begin to affect JSW measurement precision[22]. Small variations in knee rotation that occur during patient radiography do not affect JSW measurement precision[6,7].

Reproducibility in radio-anatomic joint positioning

Reproducibility in repositioning the joint radio-anatomically is determined from the measurement of the difference in the medial tibial rim alignment, obtained from repeat radiographs[7]. With correct radioanatomic positioning of the knee in the fluoroscopic semiflexed view, the central ray of the X-ray beam passes through the middle of the tibiofemoral joint space so that the beam is parallel with the centre of the medial tibial plateau[6–8]. With non-fluoroscopic methods, the effect of anatomical variability among patients (due to the angle at which the medial tibial plateau is inclined posteriorly in the MTP view and to the girth of the thigh in the fixed flexion method) a proportion of the films will exhibit anterior and posterior tibial rims that are not superimposed but are separated by a small gap. The degree of similarity in this inter-rim gap (Fig. 7), measured from test/retest radiographs, determines the reproducibility in radioanatomic repositioning of the knee. Published values for X-ray technologists reproducibility in repositioning the knee showed that for the fluoroscopic semiflexed method the median (95% CI) of the absolute value of the difference in tibial inter-rim distance between test- retest was 0.03 (0.02, 0.04) mm for 146 film pairs from 26 technologists in North America, and 0.25 (0.05, 0.29) mm for the 120 EU film pairs from 24 technologists in Europe[23]. For the non-fluoroscopic MTP method the median (95% CI) of the absolute value of the difference in tibial inter-rim distance between test- retest was 0.035 (0.03, 0.04) mm for 98 NA film pairs from 30 North American technologists[24,25]. Although similar data was not available for the non-fluoroscopic fixed-flexion method, the mean (SD) absolute change in tibial inter-rim distance for this method in 42 OA patients, radiographed at baseline and 1 year later was 0.47 (0.53) mm[26]. The results from both the fluoroscopic semi-flexed and the non-fluoroscopic MTP methods obtained from multicentre clinical trials, confirm that both methods reliably reposition the tibial between examinations, and that this is also likely to be case for the fixed flexion method.

Are anatomic differences in knee position between methods reflected in JSW measurement precision from multicentre clinical trials?

Published values for minimum medial compartment JSW measurement reproducibility in OA knees X-rayed in the fluoroscopic semiflexed, the non-fluoroscopic MTP and fixed flexion positions have been obtained from test/re-test measurements of duplicate films. For the fluoroscopic semi-flexed method, data was obtained from 50 clinical X-ray technologists (26 from North America (NA) and 24 from the European Union (EU)) who X-rayed five knees twice within 2 to 7 days, in 199 (111 F) patients with medial compartment OA[23]. The standard deviation (SD) of the mean difference in JSW between test and re-test was 0.16 mm for 146 NA film pairs, and 0.18 mm for the 120 EU film pairs. In the non-fluoro MTP method, 30 clinical X-ray technologists from 22 sites across NA X-rayed knees twice on same day in 402 (269 F) patients with medial compartment OA[24,25]. The standard deviation (SD) of mean difference in JSW between test and re-test was 0.09 mm for 767 film pairs, assessed both at baseline and at one year follow up. In the non-fluoroscopic fixed flexion method, technologists from 5 NA sites X-rayed knees twice within 2 to 4 weeks in 85 (67 F) patients with medial compartment OA[27]. The standard deviation (SD) of mean difference in JSW between test and re-test was 0.17 mm for 170 film pairs.

Comparing these findings with published values reported for OA knees radiographed with the three semiflexed knee protocols are given in Table I. They show that, apart from one exception, JSW precision values appear to be smaller in the MTP compared to the fluoroscopic semiflexed and fixed flexion methods. More studies are required to determine whether there is any significant difference in JSW measurement precision between the methods with respect not only to short-term precision (described above) but also their performance in long-term trials (of which there is little data at present). The larger values cited for JSW measurement precision in the fluoroscopic semiflexed and MTP methods (Table I) were obtained from the same center and could be attributed to variability in that centers radiograph procedure[23].

Summary of anatomical differences between fluoro and non-fluoro MTP and Fixed flexion views

Although, each of the radiographic methods standardizes the angle of the tibia differently, the angle achieved between the femur and tibia at the joint is broadly similar between the three views, i.e. all are radioanatomically in the semiflexed position. The difference in the degree of knee flexion between patients, in the fluoroscopic semi-flexed method due to normal variation in the inclination of the tibial plateau and to differences in thigh girth in the fixed flexion method, appear not to alter the plane for JSW measurement as the work of Freeman and his colleagues[13–15] has shown that in the semiflexed knee, the medial femoral condyle displaces minimally relative to the tibial plateau over the range in flexion encountered at the joint in these radiographic methods. In the non-fluoroscopic MTP method the similarity in the angle at the tibio-femoral joint, both within and between patient knees ensures that the section plane for JSW measurement remains consistent between knee radiographs. In a recent study of the MTP method[25] excellent JSW measurement precision was achieved in this semiflexed view by ensuring that the joint was repositioned reproducibly between examinations. This factor was found to be more important in determining JSW measurement precision than in having the central ray of the X-ray beam aligning with the medial tibial plateau. Further studies, based upon head to head comparison between the three methods would be required to better characterize the differences or similarities between the views.

Table I
Comparison of the precision in JSW measurements obtained for different semiflexed methods of radiography of the knee

X-ray method	No. of knees	SD mm	No. of X-ray hubs	Reference no.
Fluoro/Semiflexed	25	0.19	1	9
Fluoro/Semiflexed	174	0.32	2	31
Fluoro/Semiflexed	129	0.16	50	23
MTP	148	0.08	1	7
MTP	20	0.08	1	28
MTP	38	0.23	1	29
MTP	767	0.09	22	24,25
Fixed flexion	50	0.16	1	27
Fixed flexion	149	0.17	5	27

Other causes for JSW variability-increase in JSW

A number of investigators have found when examining the changes in JSW in individual patients from longitudinal studies an increase, rather than a diminution, in the values for minimum medial compartment JSW measurements from semiflexed knee films[30,11]. Apart from the possibility that cartilage may have undergone some repair, there are a number of factors that can account for these observations.

- At baseline the medial compartment JSW measurement is found to be smaller than that in the lateral compartment, thereby meeting the eligibility criteria for acceptance into the study. With OA progression, joint space narrowing in this knee is greater in the lateral compartment, resulting in an increase in the JSW measured in the medial compartment.
- Ligament laxity from articular cartilage loss occurs in knees with advanced OA and can result in joint subluxation. Because of the focal nature of articular cartilage loss in OA, joint subluxation can result in the displacement of the femur upon the tibia and an altered site for JSW measurement at successive X-ray examinations.
- Joint subluxation, associated with ligament laxity, can also result in the entrapment of all or part of the meniscus in the medial compartment. This would lead to marked increase or decrease in JSW measurement between successive radiographs as shown recently by Brandt *et al.* in their figure 6[11]).

Radiological differences between fluoroscopic and non-fluoroscopic methods for positioning OA knees

The success of longitudinal OA knee clinical trial in quantifying structural changes is dependent upon the sensitivity of the imaging system to detect small anatomical changes characteristic of the disease process, and just as important, in reducing to a minimum sources of variability within the radiographic process. Any such variability makes it more difficult to detect anatomical changes recorded in the image. Minimizing variability in the radiographic process depend upon:

- Ensuring consistency and comparability in the performance of the clinical X-ray technologists throughout the study period. The quality of these technologists is determined by their training.
- The quality control procedures applied to all films to ensure that those accepted are of a consistently high standard necessary for computerized or manual methods of measurement.

The financial burden is a major factor in all longitudinal clinical trial, not only in terms of expenditure on equipment and personnel but also in respect of the study duration. Radiological factors determining the study duration include inter alia the time to train the technologists, quality control for film acceptance and the patient's time in the X-ray unit. There are major differences in these factors between the fluoroscopic and non-fluoroscopic methods, which are listed in Table II. The differences affect study costs, the technologists operating time and film processing and measurement.

FACTORS AFFECTING STUDY COSTS

Costs relating to equipment use are greater in the fluoroscopic than non-fluoroscopic methods. Among the non-fluoroscopic methods the fixed flexion procedure uses a specially designed and manufactured stereotaxic frame for positioning the patients.

In the fluoroscopic method, the greatest expenditure is in the technologists training. The period of instruction and hands on experience is greater than for the non-fluoroscopic methods. It also requires a number of patients for the technologists to practice positioning the knee so as to meet the training procedure criteria[23]. Differences in the standards of training between clinical trials can affect the technologist's performance at radiographic units as seen by differences JSW measurement reproducibility between studies[23,31] (Table I). By comparison, technologists' training for the non-fluoroscopic MTP technique is simple[6,7,24,25]. Although, it requires the use of a radiographic facility for demonstration, the X-ray tube is not operated nor does it require patients to practice the method. A number of technologists (e.g. 15) can be trained at the same time within a two-hour period[24,25]. There is no published information for the fixed flexion method, although, it can be assumed that technologists training would be similar to that for the MTP.

FACTORS AFFECTING X-RAY TECHNOLOGISTS OPERATING TIME

Compared to the non-fluoroscopic methods, positioning the knee under fluoroscopic guidance is demanding for the technologists. Correct and reproducible positioning of the knee is dependent upon the technologist's ability to operate the fluoroscopic equipment, to correctly interpreting the image of the knee on the fluoroscope monitor, to instruct the patient to move their leg into the correct position and to obtain an image of the joint that meets the radiographic quality control criteria for film acceptance. The major component of the technologists training, prior to the start of the study, concerns the development of these skills. Further, the demands of this procedure can lead to errors in the radiographic process. These errors increase with time from the initial period of training. For this reason and others related to changes in equipment and/or personnel, senior technologists are appointed to monitor the quality of the radiographic output from each X-ray facility in multicentre clinical trials[23]. Failure to do so risks sacrificing the consistency in the performance of each X-ray unit. By contrast, the technologists when positioning the leg in the non-fluoroscopic MTP or fixed flexion method find the process easy. They only have to position the patient's leg with respect to the X-ray beam and film/cassette, a procedure that is part of their basic training and in which they have considerable experience. Because of the ease in carrying out this procedure, X-ray hub supervision is minimal and can be undertaken by the regional quality control center. This center would audit both the hub's performance from an assessment of the quality control criteria for film acceptance, as well as patient's eligibility for study inclusion.

The fluoroscopic procedure for positioning each knee is time consuming. It can lead to the patient spending up to 45 min in the unit; they are also exposed to larger amounts of radiation than those attending the non-fluoroscopic procedures. Patient's time in the unit during the latter procedures is much shorter and depends on the number of radiographs taken. For the MTP view this is a single film for both knees, whereas the fixed flexion uses either two, one for each knee, or a single film for both knees.

Among the technologist's duties is the checking the exposed film against the quality control criteria for film acceptance. We have found that technologists who perform this task have a high degree of commitment to the study and that the overall radiographic quality is greatly improved compared to studies in which the task is handed over to

Table II

Radiological differences between the fluoroscopic semi flexed[23] and non-fluoroscopic MTP[7,24,25] and the fixed flexion[10,27] methods of positioning the knee in OA clinical trials

	Radiographic method		
	Fluoro/Semiflexed	MTP	Fixed flexion
Factors affecting study costs			
Equipment	Specialized	Standard	Standard + frame
Techs. training time	3–4 days	<2h	<2h
Patients for techs. training	5/tech	None	None
Techs. training cost	Significant	Modest	Modest
Factors affecting techs operating time			
X-ray unit operation	Demanding	Simple	Simple
X-ray hub supervision	Applied	Minor	Minor
No. of films/visit	2	1	2(1)
Patient time in unit	40–45 min	20 min	30 min (20 min)
Radiation	Definite	Modest	Modest
Factors affecting film processing & measurement			
Film handling, digitisation & disc storage space	X2	X1	X2 (X1)
Correction for radiographic magnification	Yes	No	No (yes)
Parallax error in film	No	No	Yes

a radiologist or other specialist[23]. Major differences exist between the fluoroscopic and non-fluoroscopic methods in the quality control criteria for film acceptance. In the former there are 16 criteria within four areas to be checked; four criteria for the radioanatomic position of the joint, four related to factors regarding correction for radiographic magnification, three for the patient's ID and five for the radiographic properties of the film[23]. The quality control criteria for the non-fluoroscopic methods are less demanding, the MTP method has nine criteria for checking all of which are normally required during routine standard radiography. There are four criteria related to the correct position of the knee on the film, two for the patient's ID and three for radiographic procedures including the use of optimal radiographic exposure for the joint[24,25]. The criteria for fixed flexion have yet to be published but can be assumed to be comparable to the MTP method.

Factors affecting film processing and measurement

Procedures in which both knees are radiographed separately, the fluoroscopic semiflexed and fixed flexion methods, double the amount of time associated with film handling and film digitization compared to the MTP method in which a single exposure is obtained. Additionally, disc storage space for each digitized image is also doubled in the former compared to the latter. A major limitation of the fluoroscopic method is the need to correct for the effect of radiographic magnification[9]. This imposes a significant burden upon the study procedure, which is not required for the non-fluoroscopic methods, although it is an option available in the fixed flexion method[10]. Further, as described above, the sectional plane for JSW measurement in the fixed flexion view is not parallel to the film (Fig. 4C). For this reason the X-ray positioning frame employed by this procedure incorporates a method to correct the parallax error.

Conclusions

Of the four radiographic methods reviewed in this paper, the standing extended knee position is the oldest. It was recommended by Alhback in 1968 as a more appropriate method for imaging the knee as the joint was under load and would better demonstrate joint space loss than knees radiographed in the supine position[32]. Recent studies have shown that this is not a reliable method for assessing joint space loss[7,9,12], not only because of the variability in knee position within and between patients[33] but, as shown here, the sectional plane for JSW measurement assesses articular cartilage that is not under load (Fig. 1D, Fig. 2 & Fig. 4A) and therefore does not assess its thickness compared to that measured in the semiflexed position[5] and is therefore poor at evaluating disease progression from the degree of joint space narrowing[7]. Further, JSW measurement in extended knee radiographs has a definite parallax error (Fig. 4A). Nonetheless, this method remains useful clinically for confirming the presence of OA, since it allows the extent of osteophyte formation to be graded[34].

Subsequently, the deployment of standardised protocols of the knee in the standing semiflexed view positioned under fluoroscopic guidance[8,9] ensured that the joint was reproducibly repositioned at repeat examinations. The sectional plane for JSW measurement has been shown to accurately and reliably measure articular cartilage thickness in the weight-bearing region of the medial diseased compartment[5] and to quantify disease progression[30,35].

Compared to the non-fluoroscopic methods, the use of the fluoroscopic semiflexed knee method in clinical trials is expensive and demanding upon the X-ray technologists who have to be trained to achieve and maintain a high standard of performance throughout the trial. The future use of this method is in doubt because the non-fluoroscopic methods are not only less expensive and technically less demanding but also because of the current trend in replacing fluoroscopic tubes by digital imaging systems. The later will render the fluoroscopic method increasingly difficult since there will be a need to ensure consistency in the output of the digital imaging systems between different X-ray hubs as well as introducing additional technical challenges, including the accurate measurement of the ball bearing for correcting for the effect radiographic magnification. Under these circumstances a viable alternative to the semiflexed fluoroscopic method, since it does not require a metal ball for radiographic magnification correct, is the Lyon-Schuss fluoroscopic protocol[36] in which the knee position is similar to the fixed flexion method, with the addition that the X-ray beam is aligned, under fluoroscopic guidance, with the tibial plateau. As a fluoroscopic protocol it is still subject to greater expense and operating costs than the non-fluoroscopic methods.

There is a slowly increasing literature on the detection of joint space narrowing in cohorts of patients with knee OA, using either fluoroscopic[30,35,37] or non-fluoroscopic[25,37] methods. It is still unclear how each of these methods performs in real life longitudinal study settings. Only when such information is available can it be used, together with factors such as cost, to assist in choosing the optimal method for a given study or research objective.

For the above reasons the non-fluoroscopic methods of the MTP and fixed flexion are the procedures that are most likely to be used in the future. In both methods the sectional plane for JSW measurement is similar and each reliably assesses articular cartilage thickness in the weight bearing area of the joint. However, there are two differences between these methods. In the fixed flexion view the patient's thigh girth results in a variable degree of joint flexion between patients (Fig. 6), by comparison, in the MTP view the degree of joint flexion is similar within and between patients. Additionally, JSW measurement in the fixed flexion method has a parallax error (Fig. 4C) due to the plane of measurement not being parallel to the film. Whether these differences between the methods have any effect upon the sensitivity at detecting disease related changes has yet to be determined. Other factors may contribute to the preferential use of one method over the other, which could include the patient's reluctance to press their painful knees against the film/cassette in the fixed flexion procedure or the technologist's personal preference for one of the methods.

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